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ABSTRACT

Reported are the findings of five descriptive studies in which the Group Assessment of Logical Thinking (GALT) was used as measure of logical thinking. Specifically, an attempt was made to determine how reliably the GALT measured logical thinking abilities and how well it predicted academic achievement. The reliability coefficients on the GALT for the five samples ranged between .76 and .86. In addition, the individual logical reasoning mode scores on the GALT and the GALT total score were predictors of academic achievement. The results seem to support the use of the GALT as a reliable measure of logical thinking. (Author)

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Is the GALT a Reliable Instrument for Measuring the Logical Thinking Abilities of Students in Grades Six through Twelve?

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Abstract

The purpose of this paper was to integrate the findings of five descriptive studies in which the Group Assessment of Logical Thinking (GALT) was used as measure of logical thinking. Specifically, an attempt was made to determine how reliably the GALT measures logical thinking abilities and how well it predicts academic achievement. The reliability coefficients on the GALT for the five samples ranged between .76 and .86. In addition, the individual logical reasoning mode scores on the GALT and the GALT total score were predictors of academic achievement. The results seem to support the use of the GALT as a reliable measure of logical reasoning.

Is the GALT a Reliable Instrument for Measuring the Logical Thinking Abilities of Students in Grades Six through Twelve?

Five formal operational modes (i.e., proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning) have been recognized as essential for successful achievement in upper level science and mathematics courses (Bitner, 1986a; Capie, Newton, & Tobin, 1981; DeCarcer, Gabel, & Staver, 1978; Lawson, 1985). Therefore, reliable instruments are needed to measure formal operational reasoning (i.e., logical thinking). Since the Piagetian clinical method for assessing logical thinking has some obvious drawbacks, namely that of objectivity and sampling of large number of subjects, objective group measures of logical reasoning have been constructed (Lawson, 1978; Raven, 1973; Roadrangka, Yeany, & Padilla, 1982; Tobin & Capie, 1981).

A recently developed instrument of logical thinking the Group Assessment of Logical Thinking (GALT) (Roadrangka et al., 1982, 1983), a twenty-one item paper and pencil test, measures six reasoning modes (conservation, proportional reasoning, controlling variables, probabilistic

reasoning, correlational reasoning, and combinatorial logic). The test items on the GALT were adapted from Lawson, Burney, and Longeot (Roadrangka et al., 1982). The first eighteen test items on the GALT require the student to select the correct response and justification to receive credit for the item. For test items 19, 20, and 21, the student must show a pattern for the combinations. Classification of students as concrete, transitional, or formal reasoners on the twenty-one item GALT is as follows: (a) 0-8, concrete; (b) 9-15, transitional; and (c) 16-21, formal. Roadrangka et al. (1983) reported that only 14% of the students were classified as formal operational as measured by the GALT and Piagetian Interview Tasks.

To validate the GALT, the instrument was administered to 628 students in grades six through college (Roadrangka et al., 1983). They (Roadrangka et al., 1983) reported a coefficient alpha of .85 for the total test with subtest reliabilities ranging between .37 and .83. The test analysis indicated that correlational (.11) and proportional (.16) reasoning were the most abstract. Construct validity was established by correlating the scores on the GALT with scores on the Piagetian Interview Tasks and by computing the

principal components factor analysis on the individual test items and six test modes. The correlation coefficient between the GALT and the interview tasks was .80. The principal components factor analysis for the individual test items yielded a two factor solution with loadings between .28 (correlational reasoning) and .73 (probabilistic reasoning) on Factor One. Only the conservation of mass items loaded on Factor Two. The results of the factor analysis of the six subtests indicated a single-factor solution with loadings ranging between .44 and .70. Also, criterion-related validity of the GALT was established by correlating the scores on the GALT with the scores on the Test of Integrated Process Skills (TIPS II). A .71 correlation coefficient was found between the total GALT and the total TIPS II.

The purpose of this paper was to integrate the findings of five descriptive studies in which the GALT was used as the measure of logical thinking (Bitner, 1986a, 1986b, 1987a, 1987b, 1987c) Specifically, an attempt was made to determine how reliably the GALT measures logical thinking abilities and how well it predicts academic achievement.

Method

Sample

Five separate convenience samples were used in this study. The five samples are as follows: (a) eighth grade students (N = 147), (b) sixth through twelfth grade students in a private school (N = 196), (c) seventh through twelfth grade students in a rural school (N = 156), (d) seventh grade earth science students in a rural school (N = 40), and (e) secondary general science students in a rural school (N = 43). In all cases except the eighth grade sample, all students in the either the class or grade levels were included in the sample. For the eighth grade sample, students in resource or self-contained special education classes were excluded from the sample.

Instrument

The instruments used in these studies are the total GALT or abbreviated GALT (Roadrangka et al., 1982) and the Science Research Achievement Battery (SRA). As previously stated, the total GALT contains twenty-one items measuring six reasoning modes (i.e., conservation, proportional reasoning, controlling variables, probabilistic reasoning, correlational, and combinatorial reasoning). Likewise, the twelve-item abbreviated GALT measures the six reasoning modes.

The abbreviated GALT was administered to all samples except the seventh grade earth science students (N = 40) and the secondary general science students (N = 43).

Statistical Analysis of Data

For each of the five samples, an item analysis, means and standard deviations, principal components factor analysis, frequency and percentages, t-test of independent samples, and one-way analysis of variance were computed. In addition, a stepwise multiple regression was computed for the eighth grade sample.

Results

The item analysis of the GALT yielded the following results: (a) Item difficulty for eighth grade sample (N = 147) ranged between .21 (item 17 correlational reasoning) and .82 (item 1 conservation of matter) for the twelve items with subtest ranges between .29 (correlational reasoning) and .73 (conservation). The K-R 20 reliability coefficient was .76 (see Table 1). (b) For the sixth through twelfth grade private school students (N = 196), the item difficulty for the twelve items ranged between .36 (item 17 correlational reasoning) and .91 (item 1 conservation of matter) with difficulty levels between .29 (correlational reasoning) and .73

(conservation) for the subtests. The K-R 20 coefficient was .86. (c) The item difficulty range on the twelve-item GALT for the sixth through twelfth grade rural school sample (N = 156) was .21 (item 20 combinatorial reasoning) to .81 (item 1 conservation of matter). The K-R 20 coefficient was .83 (see Table 3). (d) The item difficulty of the total GALT for the earth science sample (N = 40) ranged between .03 (item 21 combinatorial reasoning) and .94 (item 1 conservation of matter) with subtests ranging between .33 (correlational reasoning) and .71 (conservation). The K-R 20 coefficient was .86 (see Table 4). (e) The item difficulty of the total GALT for the secondary general science sample (N 43) ranged between .02 (item 21 combinatorial reasoning) and .85 (item 2 conservation of matter) with subtests falling between .24 (proportional reasoning and probabilistic reasoning) and .64 (conservation). The K-R 20 coefficient was .78 (see Table 5).

The means and standard deviations are reported in Tables 6-10. The means for the twelve-item GALT ranged between 3.78 and 5.63, whereas the means for the twenty-one item GALT were 8.46 and 5.05.

The results of the principal components factor analyses indicated two to four factors (see Tables 11-15). Reported in the tables are the factor

loadings and percent of variance explained.

In Tables 16-19 are reported the frequencies and percentages of students per reasoning mode. Only 7% of the eighth grade students (N = 147) were functioning at the formal operational level as measured on the abbreviated GALT. Thirty-one percent of the sixth through twelfth grade students in a private school (N = 196) were functioning at the formal operational level as measured by the abbreviated GALT. For the seventh through twelfth grade rural students (N = 155), 12% were functioning at the formal operational level. None of the secondary general science students (N = 43) were functioning at the formal operational level as measured by the total GALT, whereas 7% of the seventh grade earth science students (N = 40) were functioning at the formal operational level as measured by the total GALT.

The results of the one-way analysis variance for GALT total score by gender were not significant for any of the samples; however, the results of the independent T-test indicated gender differences for some items and modes of reasoning (see Tables 20, 22, and 23). Gender differences were not found for the sixth through twelfth grade students (N = 196) and the secondary general science students (N = 43) (see Tables 21 and 24). All gender differences

except those in the area of combinatorial reasoning were in favor of the males.

The results of the stepwise multiple regression with the six reasoning modes as the independent variables and science achievement as measured by the SRA as dependent variables were significant at the .0001 level (see Bitner, 1986a).

Conclusions

The results of the test analyses seemed to indicate that items 8 (proportional reasoning), 17 (correlational reasoning), and 20 (combinatorial reasoning) were the most difficult for the three samples completing the abbreviated GALT. On the total GALT for two samples, items 7 (proportional reasoning) and 21 (combinatorial reasoning) were the most abstract. Although there was some variance in the mode difficulty across the samples, the correlational reasoning mode seemed to present problems for all samples as was found by Roadrangka et al. (1983). The reliability coefficients for the abbreviated GALT ranged between .76 and .86. On the total GALT, the reliability coefficients were .78 and .86. Roadrangka et al. found a .85 alpha coefficient on the total GALT.

The results of the principal components factor analyses for the five samples yielded two to four factor solutions which differed from Roadrangka et

al.'s (1983) finding of a two factor solution for the principal components analysis. The results of the factor analysis of the six reasoning modes of the five samples reported in this paper support Roadrangka et al.'s single-factor solution (see Tables 11-15).

The majority of students in these five samples (i.e., 7% (N = 147), 31% (N = 196), 12% (N = 156), 0% (N = 43), and 7% (N = 40) are not functioning at the formal operational level as measured by the GALT.

Gender differences in logical thinking ability as measured by the GALT were few. Those that were found favored the males except in the area of combinatorial reasoning. Differences in favor of the males were found for the proportional reasoning mode and specifically items 4 (conservation), 5, 6 , 7, 8 (proportional reasoning), 16 (probabilistic reasoning) and 17 (correlational reasoning).

The results across the five samples are quite consistent which seem to indicate that the GALT is a reliable measure of logical thinking.

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Table 1

Test Analysis Results of the GALT (N = 147)

Item	Item Difficulty	Discrimination Index	M	SD
Mode 1: Conservation				
#1 Piece of Clay	.82	.32	.80	.40
#4 Metal Weights	.63	.50	.61	.49
Subtest: Conservation (#1 and #4)	.73		1.39	.65
Mode 2: Proportional Reasoning				
#8 Glass Size #2	.42	.43	.12	.32
#9 Scale #1	.53	.39	.33	.47
Subtest: Proportional Reasoning (#8 and #9)	.37		.43	.62
Mode 3: Controlling Variables				
#11 Pendulum Length	.72	.49	.27	.45
#13 Ball #1	.42	.44	.24	.43
Subtest: Controlling Variables (#11 and #13)	.39		.52	.68
Mode 4: Probabilistic Reasoning				
#15 Squares and Diamonds #1	.38	.51	.17	.38
#16 Squares and Diamonds #2	.43	.56	.23	.42
Subtest: Probabilistic Reasoning (#15 and #16)	.41		.40	.73
Mode 5: Correlational Reasoning				
#17 The Mice	.21	.24	.12	.33
#18 The Fish	.37	.29	.04	.20
Subtest: Correlational Reasoning (#17 and #18)	.29		.16	.39
Mode 6: Combinatorial Reasoning				
#19 The Dance	.69	.67	.69	.46
#20 The Shopping Center	.39	.71	.39	.49
Subtest: Combinatorial Reasoning (#19 and #20)	.53		1.09	.66

Note 1. For Items 1-18, the KR-20 is .76. The KR-20 reliability coefficients for each eighth grade section are .65 (algebra), .75 (8-1), .69 (8-2), and .52 (8-3).

Table 2

Test Analysis for Items in the Abbreviated GALT (N = 196)

Item	Item Difficulty	Discrimination Index	M	SD
#1 Piece of Clay	.91	.38	.89	.31
#4 Metal Weights	.75	.44	.74	.44
Mode 1: Conservation (#1 and #4)	.83		1.63	.60
#8 Glass Size #2	.47	.59	.37	.48
#9 Scale #1	.58	.43	.41	.49
Mode 2: Proportional Reasoning (#8 and #9)	.53		.78	.82
#11 Pendulum Length	.56	.62	.50	.50
#13 Ball #1	.60	.59	.45	.50
Mode 3: Controlling Variables (#11 and #13)	.58		.95	.84
#15 Squares and Diamonds #1	.57	.62	.42	.50
#16 Squares and Diamonds #2	.59	.67	.44	.50
Mode 4: Probabilistic Reasoning (#15 and #16)	.58		.87	.94
#17 The Mice	.36	.25	.27	.44
#18 The Fish	.47	.31	.10.	.30
Mode 5: Correlational Reasoning (#17 and #18)	.42		.37	.59
#19 The Dance	.58	.58	.58	.50
#20 The Shopping Center	.46	.45	.46	.50
Mode 6: Combinatorial Reasoning (#19 and #20)	.46		1.04	.82

Note 1. For Items 1-20 (KR-20 = .86).

Table 4

Test Analysis Results of the GALT (N = 40)

Item	Item Difficulty	Discrimination Index	M	SD
#1 Piece of Clay	.94	.21	.90	.30
#2 Test Tube	.91	.28	.85	.36
#3 Road	.61	.45	.58	.50
#4 Metal Weights	.38	.25	.70	.46
Mode 1: Conservation (1,2,3,4)	.71		2.88	1.29
#5 Plastic Jar #1	.44	.05	.25	.44
#6 Plastic Jar #2	.28	.34	.15	.36
#7 Glass Size #1	.35	.36	.15	.36
#8 Glass Size #2	.39	.54	.28	.45
#9 Scale #1	.49	.47	.33	.47
#10 Scale #2	.58	.42	.35	.48
Mode 2: Proportional Reasoning (5,6,7,8,9,10))	.42		1.45	1.60
#11 Pendulum Length	.38	.33	.20	.41
#12 Pendulum Weight	.45	.43	.35	.48
#13 Ball #1	.39	.62	.30	.46
#14 Ball #2	.45	.44	.33	.47
Mode 3: Controlling Variables (11, 12, 13,14)	.42		1.18	1.43
#15 Squares and Diamonds #1	.45	.46	.25	.44
#16 Squares and Diamonds #2	.44	.51	.35	.48
Mode 4: Probabilistic Reasoning (15, 16)	.45		.60	.84
#17 The Mice	.23	.47	.15	.36
#18 The Fish	.43	.30	.10	.30
Mode 5: Correlational Reasoning (17, 18)	.33		.23	.48
#19 The Dance	.78	.27	.75	.44
#20 The Shopping Center	.28	.61	.30	.46
#21 Light Box	.03	.38	.18	.68
Mode 6: Combinatorial Reasoning (19, 20, 21)	.36		1.08	.69

Note 1. For Items 1-21 (KR-20 = .86), Mode 1 (K-R 20 = .75), Mode 2 (K-R 20 = .67), Mode 3 (K-R 20 = .81), Mode 4 (K-R 20 = .75), Mode 5 (K-R 20 = .55), Mode 6 (K-R 20 = .11)

Table 3

Test Analysis for Items on the Abbreviated GALT (N=156)

Item	Proportion Correct	Discrimination Index	Mean	Standard Deviation
Mode 1: Conservation	.70			
#1 Piece of Clay	.81	.45	.78	.41
#4 Metal Weights	.58	.46	.54	.50
Mode 2: Proportional Reasoning	.37			
#8 Glass Size #2	.24	.52	.15	.36
#9 Scale #1	.50	.58	.31	.46
Mode 3: Controlling Variables	.47			
#11 Pendulum Length	.44	.58	.37	.48
#13 Ball #1	.50	.55	.41	.49
Mode 4: Probabilistic Reasoning	.40			
#15 Squares and Diamonds #1	.39	.59	.21	.41
#16 Squares and Diamonds #2	.40	.56	.20	.40
Mode 5: Correlational Reasoning	.34			
#17 The Mice	.30	.37	.15	.36
#18 The Fish	.38	.24	.03	.16
Mode 6: Combinatorial Reasoning	.33			
#19 The Dance	.44		.44	.50
#20 The Shopping Center	.21		.21	.41

Note 1. K-R 20 = .83.

Table 4

Test Analysis Results of the GALT (N = 40)

Item	Item Difficulty	Discrimination Index	M	SD
#1 Piece of Clay	.94	.21	.90	.30
#2 Test Tube	.91	.28	.85	.36
#3 Road	.61	.45	.58	.50
#4 Metal Weights	.38	.25	.70	.46
Mode 1: Conservation (1,2,3,4)	.71		2.88	1.29
#5 Plastic Jar #1	.44	.05	.25	.44
#6 Plastic Jar #2	.28	.34	.15	.36
#7 Glass Size #1	.35	.36	.15	.36
#8 Glass Size #2	.39	.54	.28	.45
#9 Scale #1	.49	.47	.33	.47
#10 Scale #2	.58	.42	.35	.48
Mode 2: Proportional Reasoning (5,6,7,8,9,10))	.42		1.45	1.60
#11 Pendulum Length	.38	.33	.20	.41
#12 Pendulum Weight	.45	.43	.35	.48
#13 Ball #1	.39	.62	.30	.46
#14 Ball #2	.45	.44	.33	.47
Mode 3: Controlling Variables (11, 12, 13,14)	.42		1.18	1.43
#15 Squares and Diamonds #1	.45	.46	.25	.44
#16 Squares and Diamonds #2	.44	.51	.35	.48
Mode 4: Probabilistic Reasoning (15, 16)	.45		.60	.84
#17 The Mice	.23	.47	.15	.36
#18 The Fish	.43	.30	.10	.30
Mode 5: Correlational Reasoning (17, 18)	.33		.23	.48
#19 The Dance	.78	.27	.75	.44
#20 The Shopping Center	.28	.61	.30	.46
#21 Light Box	.03	.38	.18	.68
Mode 6: Combinatorial Reasoning (19, 20, 21)	.36		1.08	.69

Note 1. For Items 1-21 (KR-20 = .86), Mode 1 (K-R 20 = .75), Mode 2 (K-R 20 = .67), Mode 3 (K-R 20 = .81), Mode 4 (K-R 20 = .75), Mode 5 (K-R 20 = .55), Mode 6 (K-R 20 = .11)

Table 5

Test Analysis Results of the GALT (N = 43)

Item	Item Difficulty	Discrimination Index	M	SD
#1 Piece of Clay	.77	.37	.88	.34
#2 Test Tube	.85	.30	.92	.28
#3 Road	.40	.30	.75	.44
#4 Metal Weights	.54	.41	.79	.42
Mode 1: Conservation (1,2,3,4)	.64		3.25	1.11
#5 Plastic Jar #1	.20	.25	.42	.50
#6 Plastic Jar #2	.21	.54	.25	.44
#7 Glass Size #1	.09	.20	.25	.44
#8 Glass Size #2	.21	.51	.42	.50
#9 Scale #1	.38	.41	.38	.50
#10 Scale #2	.36	.35	.33	.48
Mode 2: Proportional Reasoning (5,6,7,8,9,10))	.24		2.00	1.79
#11 Pendulum Length	.36	.39	.21	.42
#12 Pendulum Weight	.41	.41	.33	.48
#13 Ball #1	.35	.35	.38	.50
#14 Ball #2	.38	.16	.38	.50
Mode 3: Controlling Variables (11, 12, 13,14)	.38		1.30	1.52
#15 Squares and Diamonds #1	.20	.32	.33	.48
#16 Squares and Diamonds #2	.27	.51	.46	.51
Mode 4: Probabilistic Reasoning (15, 16)	.24		.79	.88
#17 The Mice	.41	.35	.25	.44
#18 The Fish	.31	.35	.08	.28
Mode 5: Correlational Reasoning (17, 18)	.36		.33	.57
#19 The Dance	.58	.21	.75	.44
#20 The Shopping Center	.23	.35	.29	.46
#21 Light Box	.02	.33	.17	.64
Mode 6: Combinatorial Reasoning (19, 20, 21)	.28		1.13	.74

Note 1. For Items 1-21 (KR-20 = .78), Mode 1 (K-R 20 = .72), Mode 2 (K-R 20 = .71), Mode 3 (K-R 20 = .73), Mode 3 (K-R 20 = .73), Mode 4 (K-R 20 = .70), Mode 5 (K-R 20 = .00), Mode 6 (K-R 20 = .56)

Table 6

Mean, Standard Deviation, and Percent on the GALT for Each Eighth Grade Section Answering Each Item Correctly

	Sections														
Reasoning	Algebra			8-1			8-2			8-3			Total		
Skills	(n = 19)			(n = 26)			(n = 83)			(n = 19)			(N = 147)		
	M	SD	%	M	SD	%	M	SD	%	M	SD	%	M	SD	%
Mode 1: Conservation															
01	.79	.42	79	.88	.33	88	.82	.39	82	.58	.51	58	.80	.40	80
04	.79	.42	79	.62	.50	62	.54	.50	54	.74	.45	74	.61	.49	61
Mode 2: Proportional Reasoning															
06	.53	.51	53	.19	.40	19	.01	.11	1	.00	.00	00	.12	.32	12
09	.58	.51	58	.50	.51	50	.23	.42	23	.26	.45	26	.33	.47	33
Mode 3: Controlling Variables															
011	.68	.48	69	.31	.47	31	.21	.41	21	.05	.23	5	.27	.45	27
013	.47	.51	47	.38	.50	38	.18	.39	18	.11	.32	11	.24	.43	24
Mode 4: Probabilistic Reasoning															
015	.47	.51	47	.38	.50	35	.07	.26	7	.00	.00	00	.17	.38	17
016	.53	.51	53	.42	.50	42	.12	.32	12	.16	.37	.16	.23	.42	23
Mode 5: Correlational Reasoning															
017	.11	.32	11	.27	.45	27	.08	.28	8	.11	.32	11	.12	.33	12
018	.05	.23	5	.04	.20	4	.05	.22	5	.00	.00	00	.04	.20	4
Mode 6: Combinatorial Reasoning															
019	.89	.32	89	.73	.45	73	.65	.48	65	.63	.50	63	.69	.46	69
020	.79	.42	79	.54	.51	54	.34	.48	34	.05	.23	5	.39	.49	39
Total	6.79	2.25		5.19	2.62		2.88	1.55		2.68	1.20		2.98	2.21	

Table 7

Mean and Standard Deviation on the GALT for 6th through 12th Grade Students Answering Each Item Correctly (N = 196)

	Grade															
Reasoning	6		7		8		9		10		11		12		Total	
Skill	(n = 26)		(n = 30)		(n = 30)		(n = 27)		(n = 30)		(n = 29)		(n = 24)		(N = 196)	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Con	1.31	.84	1.37	.61	1.70	.60	1.74	.45	1.80	.41	1.69	.60	1.83	.38	1.63	.60
01	.69	.47	.80	.41	.93	.25	.96	.19	1.00	.00	.90	.31	.96	.20	.89	.31
04	.62	.50	.57	.50	.77	.43	.78	.42	.83	.38	.79	.41	.88	.34	.74	.44
Prop Reas	.31	.55	.33	.55	.63	.72	.63	.84	1.23	.77	.93	.84	1.42	.78	.78	.82
06	.12	.33	.03	.18	.27	.45	.41	.50	.63	.49	.48	.51	.67	.48	.37	.48
09	.19	.40	.30	.47	.37	.49	.22	.42	.60	.50	.45	.51	.75	.44	.41	.49
Cont Var	.19	.57	.70	.79	.53	.63	1.07	.87	1.40	.77	1.24	.74	1.54	.59	.95	.84
011	.12	.33	.40	.50	.33	.48	.56	.51	.67	.48	.66	.48	.79	.41	.50	.50
013	.08	.27	.30	.47	.20	.41	.52	.51	.73	.45	.59	.59	.75	.44	.45	.50
Prob Reas	.19	.49	.13	.43	.50	.78	.85	.99	1.50	.82	1.34	.90	1.63	.71	.87	.94
015	.08	.27	.07	.25	.23	.43	.41	.50	.77	.43	.62	.49	.83	.38	.42	.50
016	.12	.33	.07	.25	.27	.45	.44	.51	.73	.45	.72	.45	.79	.41	.44	.50
Correl Reas	.27	.45	.17	.46	.30	.53	.30	.54	.47	.68	.45	.63	.71	.69	.37	.59
017	.23	.43	.13	.35	.20	.41	.26	.45	.30	.47	.38	.49	.38	.49	.27	.44
018	.04	.20	.03	.18	.10	.31	.04	.19	.14	.35	.07	.26	.33	.48	.10	.30
Comb Reas	.50	.65	.67	.76	.70	.75	.96	.71	1.50	.73	1.31	.81	1.71	.46	1.04	.82
019	.23	.43	.40	.50	.43	.50	.44	.51	.77	.43	.79	.41	1.00	.00	.56	.50
020	.27	.45	.27	.45	.27	.45	.52	.51	.73	.45	.52	.51	.71	.46	.46	.50
GALT Total	2.77	1.58	3.37	2.16	4.37	2.62	5.56	2.61	7.90	2.51	6.90	2.96	8.88	1.75	5.63	3.15

Table 8

Mean, Standard Deviation, and Percent on the GALT for 7th through 12th Grade Students Answering Each Item Correctly (n=156)

Reasoning Skill	Grade 7 (n=27)			Grade 8 (n=23)			Grade 9 (n=30)			Grade 10 (n=32)			Grade 11 (n=25)			Grade 12 (n=18)			Total (n=156)		
	M	SD	%	M	SD	%	M	SD	%	M	SD	%	M	SD	%	M	SD	%	M	SD	%
Con	.78	.75		1.35	.78		1.50	.68		1.53	.62		1.31	.74		1.28	.75		1.30	.75	47
01	.52	.51	52	.83	.39	83	.90	.31	90	.94	.25	94	.69	.47	69	.78	.43	78	.78	.41	78
04	.26	.45	26	.52	.51	52	.67	.48	67	.59	.50	59	.62	.50	62	.61	.50	61	.54	.50	54
Prop																					
Reas	.07	.27		.17	.49		.50	.68		.75	.84		.62	.70		.67	.69		.47	.69	11
08	.00	.00	0	.04	.21	4	.10	.31	10	.38	.49	38	.19	.40	19	.17	.38	17	.15	.36	15
09	.07	.27	7	.13	.34	13	.40	.50	40	.38	.49	38	.42	.50	42	.44	.51	44	.31	.46	31
Cont																					
Var	.22	.58		.65	.78		.83	.75		1.09	.73		.96	.77		.83	.91		.78	.79	22
011	.11	.32	11	.39	.50	39	.40	.50	40	.59	.50	59	.31	.47	31	.33	.49	33	.37	.48	37
013	.11	.32	11	.26	.45	26	.43	.50	43	.50	.51	50	.65	.49	65	.50	.51	50	.41	.49	41
Prob																					
Reas	.07	.38		.26	.62		.17	.53		.75	.95		.54	.90		.67	.91		.40	.78	18
015	.04	.19	4	.13	.34	13	.07	.25	7	.38	.49	38	.27	.45	27	.39	.50	39	.21	.41	21
016	.04	.19	4	.13	.34	13	.10	.31	10	.38	.49	38	.27	.45	27	.28	.46	28	.20	.40	20
Correl																					
Reas	.07	.27		.17	.49		.10	.31		.28	.52		.23	.43		.11	.32		.17	.41	1
017	.07	.27	7	.13	.34	13	.10	.31	10	.25	.44	25	.19	.40	19	.11	.32	11	.15	.36	15
018	.00	.00	0	.04	.21	4	.00	.00	0	.03	.18	3	.08	.27	8	.00	.00	0	.03	.16	3
Comb																					
Reas	.30	.47		.61	.72		.43	.57		.81	.78		.85	.73		.94	.67		.64	.72	14
019	.30	.47	30	.48	.51	48	.20	.41	20	.59	.50	59	.54	.51	54	.56	.51	56	.44	.50	44
020	.00	.00	0	.13	.34	13	.30	.47	30	.22	.42	22	.27	.45	27	.39	.50	39	.21	.41	21
GALT Total	1.52	1.65		1.26	2.42		1.63	1.90		5.22	1.30		4.50	2.77		4.50	1.20		3.78	2.83	

Table 9

Means and Standard Deviations on the GALT for a

a Seventh Grade Earth Science Class (N = 40)

Reasoning Mode/Skill	M	SD
Conservation	3.25	1.11
#1	.88	.34
#2	.92	.28
#3	.75	.44
#4	.79	.42
Proportional	2.00	1.79
#5	.42	.50
#6	.25	.44
#7	.25	.44
#8	.42	.50
#9	.38	.50
#10		
Controlling Variables	1.30	1.52
#11	.21	.42
#12	.33	.48
#13	.38	.50
#14	.38	.50
Probabilistic	.79	.88
#15	.33	.48
#16	.46	.51
Correlational	.33	.57
#17	.25	.44
#18	.08	.28
Combinatorial	1.12	.74
#19	.75	.44
#20	.29	.46
#21	.17	.64
GALT Total	8.46	5.15

Table 10

Means and Standard Deviations on the GALT for a a General Science Class (N = 43)

Reasoning Mode/Skill	M	SD
Conservation	2.39	1.37
#1	.84	.37
#2	.85	.37
#3	.58	.50
#4	.71	.46
Proportional	1.35	1.32
#5	.19	.40
#6	.32	.48
#7	.25	.45
#8	.28	.46
#9	.42	.51
#10	.42	.51
Controlling Variables	1.21	1.10
#11	.37	.50
#12	.59	.50
#13	.41	.51
#14	.20	.41
Probabilistic	.61	.92
#15	.29	.47
#16	.33	.49
Correlational	.39	.50
#17	.35	.49
#18	.08	.28
Combinatorial	1.03	.82
#19	.72	.46
#20	.47	.51
#21	.21	.58
GALT Total	5.05	3.38

Table 11

Factor Structure Loading for GALT Items (N = 147)

		Principal Components Varimax Rotation						
		Four Factor				Comm[e]	Single Factor	
	Reasoning Mode	F1[a]	F2[b]	F3[c]	F4[d]		Loading	/Commun
#1	Conservation of Mass				.87	.76		
#4	Conservation of Volume	.63				.45	.51	.26
#8	Proportional Reasoning	.54				.54		
#9	Proportional Reasoning	.70				.54	.68	.47
#11	Controlling Variables			.63		.46		
#13	Controlling Variables			.53		.28	.65	.42
#15	Probabilistic Reasoning			.62		.62		
#16	Probabilistic Reasoning	.53				.57	.71	.51
#17	Correlational Reasoning		.69			.66		
#18	Correlational Reasoning			.57		.43	.38	.15
#19	Combinatorial Reasoning		.64			.52		
#20	Combinatorial Reasoning			.38		.50	.59	.35
Eigenvalues		1.87	1.26	2.07	1.15	6.35	2.15	2.15

Note. Eigenvalue) 1.00.
[a]15.5% of the variance.
[b]11.5% of the variance.
[c]17.2% of variance.
[d]9.5% of variance.
[e]53.7% of variance explained.

Table 12

Factor Structure Loading for GALT Items (N = 196)

		Principal Components Analysis					
		Three Factors			Commun	Single Factor	
	Reasoning Mode	F1[a]	F2[b]	F3[c]		Loading	/Commun
#1	Conservation of Mass	.38			.50		
#4	Conservation of Volume	.34			.51	.46	.22
#8	Proportional Reasoning	.71			.62		
#9	Proportional Reasoning	.55			.45	.75	.57
#11	Controlling Variables	.70			.49		
#13	Controlling Variables	.59				.78	.60
#15	Probabilistic Reasoning	.81			.65	.82	.68
#16	Probabilistic Reasoning	.81			.68	.82	.68
#17	Correlational Reasoning			.73	.73		
#18	Correlational Reasoning		.55		.48	.48	.23
#19	Combinatorial Reasoning	.63			.45		
#20	Combinatorial Reasoning	.50			.48	.69	.48
Eigenvalues		4.13	1.31	1.07	6.50	2.77	2.77

Note 1. Eigenvalue > 1.00.
Note 2. Total explained S[a] = 54.1
[a]34.4% of the S[a].
[b]10.9% of the S[a].
[c]8.9% of the S[a].

Table 13

Factor Structure Loading for GALT Items (N = 156)

		Principal Components Varimax Rotation				
		Two Factor		Comm[c]	Single Factor	
	Reasoning Mode	F1[a]	F2[b]		Loading	/Commun
#1	Conservation of Mass		.80	.64		
#4	Conservation of Volume		.67	.45	.47	.22
#8	Proportional Reasoning	.68		.49		
#9	Proportional Reasoning	.41		.30	.72	.51
#11	Controlling Variables	.45		.32		
#13	Controlling Variables		.56	.43	.71	.50
#15	Probabilistic Reasoning	.88		.78		
#16	Probabilistic Reasoning	.86		.74	.81	.66
#17	Correlational Reasoning	.70		.49		
#18	Correlational Reasoning	.37		.14	.68	.46
#19	Combinatorial Reasoning	.46		.23		
#20	Combinatorial Reasoning	.55		.33	.71	.50
Eigenvalues		3.60	1.75	5.35	2.85	2.85

Note. Eigenvalue > 1.00.
[a]30% of the variance.
[b]14.5% of the variance.
[c]44.5% of variance explained

Table 14

Factor Structure Loading for GALT Items (N = 40)

	Principal Components Analysis						
	Four Factor				Comm[a]	Single Factor	
Reasoning Mode	F1[a]	F2[b]	F3[c]	F4[d]		Loading/Commun[f]	
#1 Conservation				.58	.82		
#2 Conservation				.61	.77		
#3 Conservation	.47				.75		
#4 Conservation	.63				.45	.63	.40
#5 Proportional Reasoning	.57				.76		
#6 Proportional Reasoning		.65			.76		
#7 Proportional Reasoning	.52				.67		
#8 Proportional Reasoning	.67				.68		
#9 Proportional Reasoning	.60				.68		
#10 Proportional Reasoning	.52				.79	.82	.40
#11 Controlling Variables	.53				.81		
#12 Controlling Variables	.44				.81		
#13 Controlling Variables	.64				.66		
#14 Controlling Variables	.63				.70	.65	.42
#15 Probabilistic Reasoning	.67				.76		
#16 Probabilistic Reasoning	.66				.84	.74	.54
#17 Correlational Reasoning	.55				.76		
#18 Correlational Reasoning	.82				.82	.62	.38
#19 Combinatorial Reasoning	.40				.66		
#20 Combinatorial Reasoning	.58				.78		
#21 Combinatorial Reasoning			.78		.82	.75	.56
Eigenvalues	5.39	2.36	2.20	1.91	15.20	2.98	2.98

Note. Eigenvalue) 1.00.
[a]25.7% of the variance.
[b]11.2% of the variance.
[c]10.5% of variance.
[d]9.1% of variance.
[e]75.7% of variance explained.
[f]49.6% of the variance explained.

Table 15

Factor Structure Loading for GALT Items (N = 43)

	Principal Components Analysis	
	Single Factor	
Reasoning Mode	Loading/Commune	
Conservation (1, 2, 3, 4)	.67	.45
Proportional Reasoning (5, 6, 7, 8, 9, 10)	.88	.77
Controlling Variables (11, 12, 13, 14)	.82	.67
Probabilistic Reasoning (15, 16)	.90	.81
Correlational Reasoning (17, 18)	.79	.62
Combinatorial Reasoning	.69	.48
Eigenvalues	3.80	3.80

Note. Eigenvalue > 1.00.
a63.4% of the variance explained.

Table 16

Proportion of Students According to the Level of Reasoning as Measured on GALT and Gender for the Four Sections of Eighth Graders

Section	Level of Reasoning					
	Formal[a]		Transitional[b]		Concrete[c]	
	F	%	F	%	F	%
Algebra (n = 19)	8	42	8	42	3	16
Male (n = 10)	5	26	5	26	0	0
Female (n = 9)	3	16	3	16	3	16
8-1 (n = 26)	3	12	13	50	10	38
Male (n = 11)	1	4	7	27	3	12
Female (n = 15)	2	8	6	23	7	27
8-2 (n = 83)	0	0	22	27	61	73
Male (n = 47)	0	0	17	20	30	36
Female (n = 36)	0	0	5	6	31	37
8-3 (n = 19)	0	0	2	11	17	89
Male (n = 16)	0	0	2	11	14	74
Female (n = 3)	0	0	0	0	3	16
Total (N = 147)	11	7	45	31	91	62

[a]Formal = Level 3, score 8-12.
[b]Transitional = Level 2, score 5-7.
[c]Concrete = Level 1, score 0-4.

Table 17

Proportion of Students According to the Level of Reasoning as Measured on the GALT and Gender for 6th through 12th-Grade Students

	Level of Reasoning					
Grade	Formal[a]		Transitional[b]		Concrete[c]	
	F	%	F	%	F	%
6th (n = 26)	0	0	3	12	23	88
Male (n = 12)	0	0	2	8	10	38
Female (n =14)	0	0	1	4	13	50
7th (n = 30)	1	3	8	27	21	70
Male (n = 16)	1	3	4	13	11	37
Female (n = 14)	0	0	4	13	10	34
8th (n = 30)	5	17	5	17	20	66
Male (n = 18)	3	10	2	7	13	43
Female (n = 12)	2	7	3	10	7	23
9th (n = 27)	6	22	10	37	11	41
Male (n = 19)	4	15	6	22	9	33
Female (n = 8)	2	7	4	15	2	7
10th (n = 30)	18	60	8	26	4	13
Male (n = 9)	6	20	2	7	1	3
Female (n = 21)	12	40	6	20	3	10
11th (n = 29)	10	35	14	48	5	17
Male (n = 11)	5	17	5	17	1	4
Female (n = 18)	5	17	9	31	4	14
12th (n = 24)	20	83	3	13	1	4
Male (n = 14)	14	58	0	0	0	0
Female (n = 10)	6	25	3	13	1	4
Total (N = 196)	60	31	51	26	85	43
Male (n = 99)	33	17	21	11	45	23
Female (n =97)	27	14	30	15	40	20

[a]Formal = Level 3, score 8-12.
[b]Transitional = Level 2, score 5-7.
[c]Concrete = Level 1, score 0-4.

Table 18

Proportion of Students According to the Level of Reasoning as Measured on the GALT and Gender for 7th through 12th Grade Students

	Level of Reasoning					
Grade	Formal[a]		Transitional[b]		Concrete[c]	
	F	%	F	%	F	%
7th (n=27)	0	0	1	4	26	96
Male (n=12)	0	0	0	0	12	44
Female (n=15)	0	0	1	4	14	52
8th (n=23)	1	4	6	26	16	70
Male (n=14)	1	4	4	17	9	39
Female (n=9)	0	0	2	9	7	30
9th (n=28)	1	4	5	18	22	79
Male (n=16)	0	0	2	7	14	50
Female (n=12)	1	3	3	11	8	29
10th (n=32)	9	28	7	22	16	50
Male (n=18)	5	17	4	13	10	31
Female (n=14)	3	10	5	16	6	19
11th (n=25)	4	16	7	28	14	56
Male (n=13)	3	12	4	15	6	23
Female (n=12)	0	15	9	35	13	50
12th (n=18)	4	23	1	6	12	71
Male (n=11)	4	22	0	0	7	39
Female (n=7)	1	6	1	6	5	28
Total (N=155)	18	12	28	18	109	70

[a]Formal = Level 3, score 8-12.
[b]Transitional = Level 2, score 5-7.
[c]Concrete = Level 1, score 0-4.

Table 19

Proportion of Students According to the Level of Reasoning as Measured on GALT and Gender for a General Science Class (N = 43) and Seventh Grade Earth Science Class (N = 40)

	Level of Reasoning					
Class	Formal[a]		Transitional[b]		Concrete[c]	
	F	%	F	%	F	%
General Science	0	0	6	14	37	86
Male (n = 26)	0	0	3	12	23	88
Female (n = 17)	0	0	3	18	14	82
Earth Science	3	7	11	28	26	65
Male (n = 24)	3	13	8	33	13	54
Female (n = 16)	0	0	3	19	13	81

[a]Formal = Level 3, score 16-21.
[b]Transitional = Level 2, score 9-15
[c]Concrete = Level 1, score 0-8

Table 20

Comparison of Males' and Females' Scores for Eighth Grade Students (N = 147) on the Subtests and Individual Items of the GALT

Item	Reasoning Skill	Significant and non-significant differences ($p < 0.01$)
Conservation		N.S.
1	Piece of Clay	N.S.
4	Metal Weights	Males > Females
Proportional Reasoning		Males > Females
8	Glass Size #1	N.S.
9	Scale #1	N.S.
Controlling Variables		N.S.
11	Pendulum Length	N.S.
13	Ball #1	N.S.
Probabilistic Reasoning		N.S.
15	Squares and Diamonds #1	N.S.
16	Squares and Diamonds #2	N.S.
Correlational Reasoning		N.S.
17	The Mice	N.S.
18	The Fish	N.S.
Combinatorial Reasoning		N.S.
19	The Dance	N.S.
20	The Shopping Center	Females > Males
	GALT Total	N.S.

Table 21

Comparison of Males' and Females' Scores for 6th through 12th Grade Students (N = 196) on the Subtests and Individual Items of the GALT

Item	Reasoning Skill	Significant and non-significant differences ($p < 0.01$)
Conservation		N.S.
1	Piece of Clay	N.S.
4	Metal Weights	N.S.
Proportional Reasoning		N.S.
8	Glass Size #1	N.S.
9	Scale #1	N.S.
Controlling Variables		N.S.
11	Pendulum Length	N.S.
13	Ball #1	N.S.
Probabilistic Reasoning		N.S.
15	Squares and Diamonds #1	N.S.
16	Squares and Diamonds #2	N.S.
Correlational Reasoning		N.S.
17	The Mice	N.S.
18	The Fish	N.S.
Combinatorial Reasoning		N.S.
19	The Dance	N.S.
20	The Shopping Center	N.S.
	GALT Total	N.S.

Table 22

Comparison of Males' and Females' Scores for 7th through 12th Grade Students (N = 156) on the Subtests and Individual Items of the GALT

Item	Reasoning Skill	Significant and non-significant differences ($p < 0.01$)
Conservation		Males > Females
1	Piece of Clay	N.S.
4	Metal Weights	Males > Females
Proportional Reasoning		N.S.
8	Glass Size #1	N.S.
9	Scale #1	N.S.
Controlling Variables		N.S.
11	Pendulum Length	N.S.
13	Ball #1	N.S.
Probabilistic Reasoning		N.S.
15	Squares and Diamonds #1	N.S.
16	Squares and Diamonds #2	Males > Females
Correlational Reasoning		N.S.
17	The Mice	N.S.
18	The Fish	N.S.
Combinatorial Reasoning		N.S.
19	The Dance	Females > Males
20	The Shopping Center	N.S.
	GALT Total	N.S.

Table 23

Comparison of Males' and Females' Scores for Seventh Grade Earth Science Students (N = 40) on the Subtests and Individual Items of the GALT

Item	Reasoning Skill	Significant and non-significant differences ($p < 0.01$)
Conservation		N.S.
1	Piece of Clay	N.S.
2	Test Tube	N.S.
3	Road	N.S.
4	Metal Weights	N.S.
Proportional Reasoning		Males > Females
5	Plastic Jar #1	Males > Females
6	Plastic Jar #2	Males > Females
7	Glass size #2	Males > Females
8	Glass Size #1	Males > Females
9	Scale #1	N.S.
10	Scale #2	N.S.
Controlling Variables		N.S.
11	Pendulum Length	N.S.
12	Pendulum Weight	N.S.
13	Ball #1	N.S.
14	Ball #2	N.S.
Probabilistic Reasoning		N.S.
15	Squares and Diamonds #1	N.S.
16	Squares and Diamonds #2	N.S.
Correlational Reasoning		N.S.
17	The Mice	Males > Females
18	The Fish	N.S.
Combinatorial Reasoning		N.S.
19	The Dance	N.S.
20	The Shopping Center	N.S.
21	Light Box	
GALT Total		N.S.

Table 24

Comparison of Males' and Females' Scores for Students in General Science Classes (N = 43) on the Subtests and Individual Items of the GALT

Item	Reasoning Skill	Significant and non-significant differences ($p < 0.01$)
Conservation		N.S.
1	Piece of Clay	N.S.
2	Test Tube	N.S.
3	Road	N.S.
4	Metal Weights	N.S.
Proportional Reasoning		N.S.
5	Plastic Jar #1	N.S.
6	Plastic Jar #2	N.S.
7	Glass size #2	N.S.
8	Glass Size #1	N.S.
9	Scale #1	N.S.
10	Scale #2	N.S.
Controlling Variables		N.S.
11	Pendulum Length	N.S.
12	Pendulum Weight	N.S.
13	Ball #1	N.S.
14	Ball #2	N.S.
Probabilistic Reasoning		N.S.
15	Squares and Diamonds #1	N.S.
16	Squares and Diamonds #2	N.S.
Correlational Reasoning		N.S.
17	The Mice	N.S.
18	The Fish	N.S.
Combinatorial Reasoning		N.S.
19	The Dance	N.S.
20	The Shopping Center	N.S.
21	Light Box	
GALT Total		N.S.